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EXPERIMENTAL STUDY THE MECHANICAL PROPERTIES OF GMAW WELDING RESULTS ON S355J2+N MATERIAL WITH POST WELD HEAT TREATMENT (PWHT)

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ABSTRAK

Assembly underframe kereta api merupakan proses penyambungan *part-part* menjadi suatu sistem yang memiliki fungsi secara kesatuan, yang prosesnya menggunakan pengelasan jenis GMAW. Dari hasil pengelasan berpotensi terbentuknya tegangan sisa yang merupakan permasalahan pada penelitian ini, sehingga diminimalisasi menggunakan metode *Post Weld Heat Treatment* (PWHT) secara *thermal*. Tujuan dari penelitian untuk mengetahui dan menganalisis pengaruh PWHT terhadap sifat mekanik dan struktur mikro baja karbon rendah jenis S355J2+N hasil pengelasan GMAW. Metode penelitian menggunakan eksperimen dengan temperatur PWHT pada 450 °C, 750 °C, dan *non*-PWHT. Untuk mengetahui sifat mekanik material, digunakan *tensile test* dan *micro vickers hardness test*. Sedangkan untuk mengetahui struktur mikro yang terbentuk digunakan *micro examination*. Hasil pengujian dibandingkan antara material pengelasan dengan PWHT dan material pengelasan *non*-PWHT. Hasil dari penelitian adalah nilai kekuatan tarik terbesar senilai 576 MPa dihasilkan pada material penggunaan PWHT temperatur 450 °C, elongasi terbesar 34,85% dihasilkan pada material dengan PWHT temperatur 750 °C, dan nilai kekerasan tertinggi 207,44 HV pada material *non*-PWHT. Kesimpulan penelitian, menunjukkan bahwa dengan bertambahnya temperatur PWHT, maka nilai kekerasan dan kekuatan tarik material semakin menurun serta terjadi peningkatan nilai keuletan material yang dipengaruhi oleh perubahan dominasi ferrite dan pearlite pada material.

Kata kunci: PWHT, GMAW, S355J2+N, sifat mekanik, struktur mikro.

ABSTRACT

Assembly underframe trains are a connecting process part-part into a system that has a unified function, the process of which uses GMAW-type welding. From the welding results, there is potential for the formation of residual stress which is a problem in this research, so it is minimized using the method Post Weld Heat Treatment (PWHT) thermal. The research aims to determine and analyze the effect of PWHT on the mechanical properties and microstructure of low-carbon steel type S355J2+N resulting from GMAW welding. The research method uses experiments with PWHT temperatures at 450 °C, 750 °C, and non-PWHT to find out the mechanical properties of materials, use the tensile test and micro-Vickers hardness test. Meanwhile, to determine the microstructure formed is used micro examination. The test results, were compared between the welding material with PWHT and the welding material non-PWHT. The results of the research are that the largest tensile strength value of 576 MPa was produced in the material using PWHT at a temperature of 450 °C, the largest elongation of 34.85% was produced in the material with a PWHT temperature of 750 °C, and the highest hardness value was 207.44 HV in the material non-PWHT. The conclusion of the research shows that with increasing PWHT temperature, the hardness and tensile strength values of the material decrease, and there is an increase in the ductility value of the material which is influenced by changes in the dominance of ferrite and pearlite in the material.

Keywords: *PWHT, GMAW, S355J2+N, mechanical properties, micro structure.*

1. INTRODUCTION

The development of technology in the industrial sector, especially railway manufacturing, requires assembly to make several parts into a single unit that has a complex function. Assembly commonly used by the manufacturing industry is the welding process. The welding process is used in the industry because it has many advantages when compared to other metal joining methods. The advantages or advantages of welding include relatively strong joints and ease of use.

The result of welding allows the emergence of undesirable phenomena or conditions such as slag or slag. Slag has a function to protect the weld from outside air. But when there is air trapped in the weld, it allows welding defects to occur, namely slag inclusion. Therefore, the manufacturing industry uses the GMAW welding method. The GMAW welding method has several advantages, such as relatively high efficiency, does not produce slag or slag in the weld, and the toughness and elasticity of the welding results are relatively good [1]. GMAW welding is an electric arc welding process, with an electric arc wrapped in gas over the welding area. Filler welding wire which has a function as an electrode is fed continuously. Shielding gases used in GMAW welding include argon, helium, or a mixture [2].

The method used to obtain qualified welding results according to standards, welding parameters are considered when welding because it determines the feasibility of a weld result. Welding refers to the WPS to qualify the weld result [3]. Parameters that are considered in GMAW welding include arc welding voltage, welding current, welding speed, electrical polarity, the amount of penetration, and standards for welding [4].

When looking at welding that does not cause slag, it does not escape the problem. The problem that often occurs in the manufacturing process is the emergence of residual stress which affects the mechanical properties of the manufacturing results [5]. If the residual stress is in the form of tensile stress that exceeds the tensile strength, it is very dangerous for the construction of the weld because it causes cracks in the weld. Removing the residual stress is done by two methods, namely thermal and mechanical methods [6].

Residual stress that occurs after the welding process has an impact on the level of strength and toughness of a material [7]. If the welding process is carried out on a train underframe that supports many other constructions above it, it becomes risky because the underframe requires tough and strong properties. From this, a thermal release of residual stress is carried out, namely PWHT which aims to release residual stress (stress relieving), increase ductility in the HAZ section, and improve weldability [8].

The study aims to determine and analyze the effect of providing Post Weld Heat Treatment (PWHT) with a holding time of 30 minutes (Nabertherm machine) on the mechanical properties and microstructure of the 12 mm thick S355J2+N low carbon steel material assembly with GMAW welding joints implemented on the UGL WAGON 60 FEET train underframe at PT INKA (Persero). Test methods to determine mechanical properties such as hardness value (HV), tensile strength (MPa), and microstructure, are carried out by tensile test, micro vickers hardness test, and micro examination.

2. METHODOLOGY

The research used low carbon steel type S355J2+N which was welded using the GMAW method with a butt joint type. After welding, the welded material was subjected to Post Weld Heat Treatment (PWHT) with temperatures of 450 °C, 750 °C and without heat treatment / non-PWHT. PWHT using a Nabertherm furnace machine is carried out on an industrial scale. Then testing of mechanical properties and microstructure is carried out, more details are written in the following sub-chapters:

2.1 *Welding*

Before welding, the 12 mm thick low carbon steel S355J2+N material is cut first with a size of 300 mm × 150 mm as many as 6 pcs using a steel cutting tool. After the material is cut, welding is then carried out using the GMAW method with a wire ER70S-6 diameter of 1.2 mm. The type of butt joint with a bevel angle of 40° with a root gap of 4 mm welding position 1G, is shown in Figure 1.

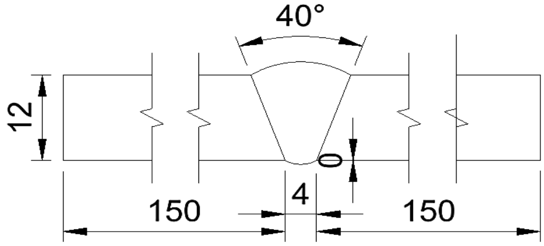

Figure 1. Welding Design

2.2 *Post Weld Heat Treatment (PWHT)*

The results of the post-welding material are then carried out Post Weld Heat Treatment (PWHT) with 3 variations, namely PWHT 450 °C, 750 °C, and non-PWHT. The trick is to put the material into the Nabertherm furnace machine. Then heat by setting the holding temperature at 450 °C and 750 °C and setting the holding time of 30 minutes, as shown in the following figures 2 and 3.

Figure 2. Furnace Machine Room

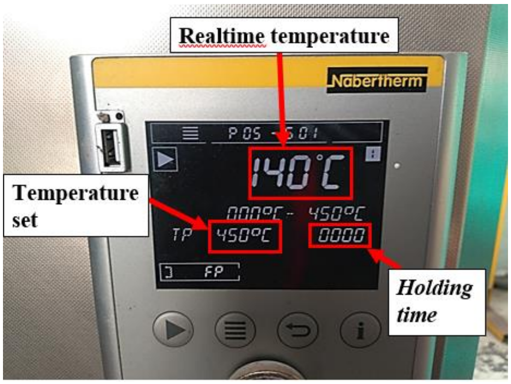

Figure 3. Furnace Machine Display

2.3 *Testing*

After the material has been PWHT, the material is cooled with room air until it has the same temperature as room temperature, and then a visual test is carried out [9]. After the visual test, then the penetrant test to find out if there are defects on the surface of the weld. If the visual test and penetrant test have been carried out, then testing the mechanical properties and microstructure of the welding material that has been carried out by PWHT, is carried out on a laboratory scale at Madiun State Polytechnic. Before testing the mechanical properties and microstructure, the material is cut according to the number of specimens needed for testing using a steel cutting machine. The types of testing include tensile test, micro-Vickers hardness test, and micro examination.

2.3.1 *Tensile Test*

Tensile tests are carried out to determine material properties in the form of plastic, elastic, and yield strength of the material [10]. From the tensile test data generated in the form of graphs, elongation values, ultimate tensile strength (UTS), and yield strength (YS). Three tests were carried out on one research variation.

2.3.2 *Micro Vickers Hardness Test*

In the process of taking Micro Vickers Hardness Test data, test specimens are indented on the side, namely the weld metal (WM), heat affected zone (HAZ), and base metal (BM) areas as shown in Figure 4, using a 136° pyramid-shaped indenter. Then observed using a microscope on the machine to see and measure the vertical and horizontal diagonal lengths. The resulting hardness value with units of HV.

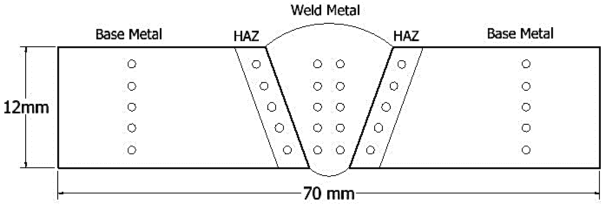

Figure 4. Indentation Point

2.3.3 *Micro Examination*

This evaluation is carried out by observing the structure of test specimens that have been given PWHT with temperatures of 450 °C and 750 °C and non-PWHT test materials using a microscope. The test results show images of the microstructure in the area tested. This evaluation is carried out to see the characteristics of the structure of the welding material.

Carbon steel from GMAW welding was cut perpendicular to the welding direction. At the initial stage, specimens are prepared based on metallographic standards, namely: cutting, framing, grinding, polishing, and etching with HNO3 etching agent for 10-15 seconds at room temperature. Then the welding area was micrographically investigated using an optical microscope with a magnification of 500x. Microstructure is a form of structural arrangement formed in metal materials and its size is very small and irregular, its shape varies according to the elements and processes experienced during its formation [11].

3. RESULTS AND DISCUSSION

This chapter describes the test results and data analysis of test specimens including micro-Vickers hardness test, tensile test, and micro examination on each heat treatment variation, namely 450 ° C, 750 ° C, and specimens without heat treatment / non-PWHT.

3.1 *Tensile Test*

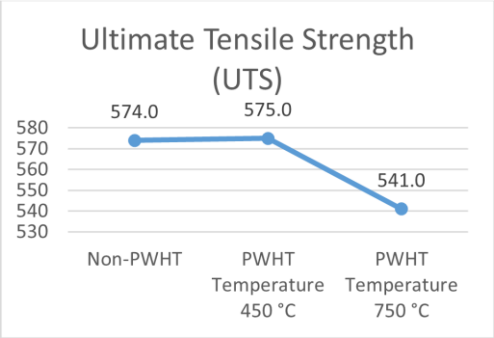

Figure 5. Comparasion of UTS

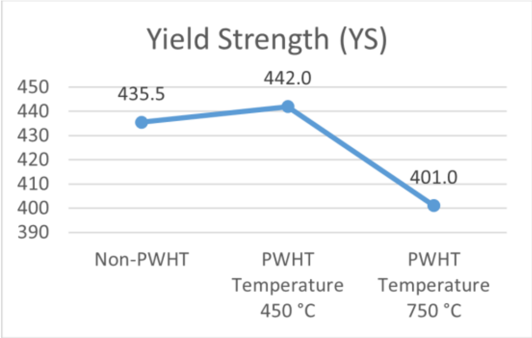

Figure 6. Comparasion of YS

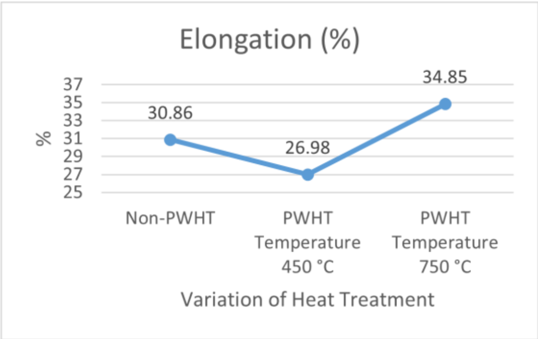

Figure 7. Comparasion of Elongation

Based on the average value of Ultimate Tensile Strength in the three heat treatment variations shown in Figure 5, it is known that the PWHT temperature of 450 °C and non-PWHT is the most optimal variation in producing the highest Ultimate Tensile Strength value with a value of 575 MPa and followed by non-PWHT specimens with 574 MPa. While the 750 °C temperature PWHT specimen produces the lowest Ultimate Tensile Strength value with a value of 541 MPa. This Ultimate Tensile Strength value is linear with the yield strength value.

As seen in Figure 7, the average value of elongation in the three PWHT variations, it is known that the PWHT temperature of 750 °C is the most optimal temperature in producing the highest elongation value with a value of 34.85%. The lowest elongation value is in the 450 °C PWHT test specimen which is worth 26.98%.

Based on the results of the tensile test, PWHT influences the UTS value of a material due to an overheated microstructure [12]. PWHT temperature affects the tensile strength value, namely the higher the PWHT temperature, the lower the tensile strength value. The higher the PWHT temperature, the higher the ductility of the welded material seen from the elongation value of the tensile test results which is linear with the hardness value of the material. This is evidenced by the highest tensile strength value in the PWHT specimen with a temperature of 450 °C whose value is almost commensurate with the non-PWHT specimen which is 1 MPa difference. This high tensile strength value is linear when associated with the hardness values of the two test specimens (PWHT 450°C and non-PWHT). Both test specimens have a higher hardness value when compared to the 750 °C PWHT specimen because the pearlite structure which has strong and hard properties is dominant in both specimen variations. High hardness values produce high tensile strength values but have low elongation values. Whereas the 750 °C temperature PWHT specimen has a low tensile strength because in this specimen the hardness value decreases in the direction of decreasing the dominance of pearlite in the microstructure of the specimen. However, the PWHT temperature of 750 °C produces the highest elongation value than other PWHT variations, in other words, PWHT at 750 ° C produces materials that have ductile properties. This is due to the ferrite structure which has ductile properties dominating in the 750 °C PWHT specimen. In the phenomenon that occurs in the tensile test results, it is known that the elongation value is inversely proportional to the tensile strength value, this means that when the tensile strength value is high, the elongation value is low [13].

3.2 *Micro Vickers Hardness Test*

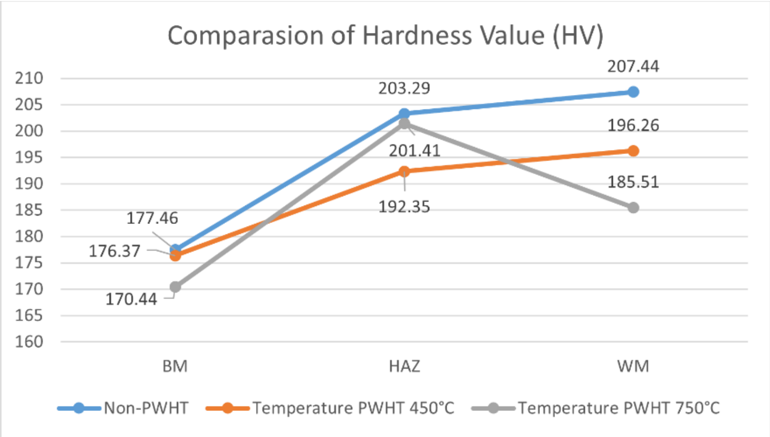

Figure 8. Comparasion of Hardness Value

From the graph shown in Figure 8, the highest hardness value is in the weld metal (WM) test area of non-PWHT specimens and heat treatment makes the hardness value in the weld metal decrease significantly with increasing PWHT temperature values used. In the HAZ area, the hardness value decreases in the 450 °C PWHT test specimen, while the 750 °C PWHT specimen does not experience a significant decrease. In the base metal (BM) test area there is a decrease with increasing PWHT temperature used but the decrease is not too significant. It is known that as the PWHT temperature increases, the hardness value of the material decreases [14].

Figure 8 shows the results of hardness values in the base metal, HAZ, and weld metal areas per PWHT variation. In the base metal area, there is no significant increase or decrease. This is because there is no significant change in the microstructure of pearlite and ferrite in the area. After all, the base metal is not the largest stress-relieving part because it is a part away from residual stress such as weld metal and HAZ. Because the most significant stress relieving is around the weld area.

While in HAZ, there is a decrease in hardness value in the PWHT variation with a temperature of 450 °C, this is directly proportional to the composition of pearlite phases in the HAZ area of 450 °C PWHT specimens whose density is lower than non-PWHT specimens and specimens with 750 °C PWHT. At a temperature of 750 °C, the hardness value in the HAZ does not decrease significantly from the non-PWHT specimen which is the variation with the highest hardness value.

In the weld metal area, there is a significant decrease in the 450 °C and 750 °C PWHT variations. The decrease in hardness value is linear with the dominance and density of the pearlite phase in the microstructure of the material. the higher the heating temperature causes the hardness value to decrease in the weld metal area. The hardness value of the material with PWHT in the weld metal is smaller than the non-PWHT material [15]. This happens because when PWHT is carried out with temperatures above the critical temperature,

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namely 723 °C, there is a change in the ferrite phase to become larger and the dominance of the pearlite phase decreases, causing the phase that was previously pearlite to turn into ferrite. This is supported by research conducted by Prabawanto and Rasyid (2018) which states that when heating reaches a critical temperature slow cooling causes carbon in the pearlite phase to decrease and has an impact on the former pearlite phase turning into ferrite.

3.3 *Micro Examination*

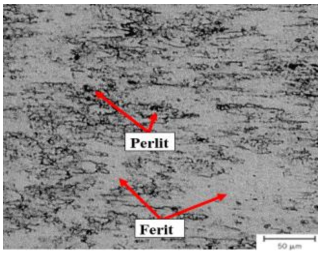
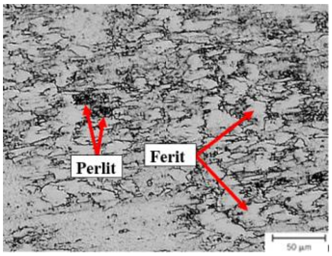
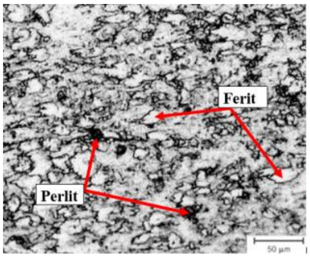
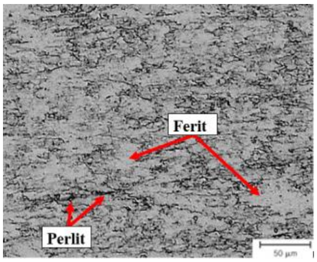
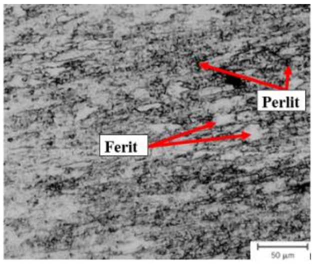
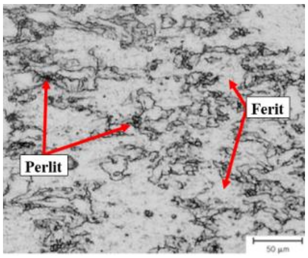
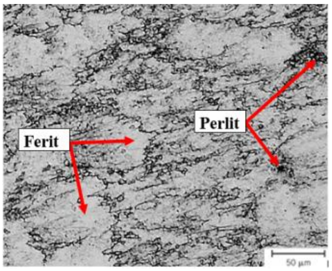
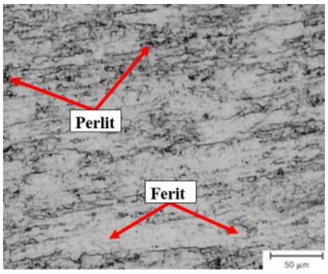
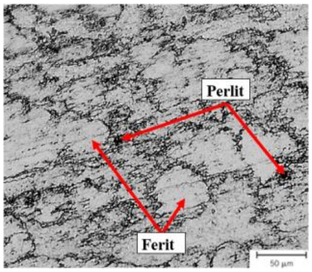
PWHT 450°C	PWHT 750°C	Non-PWHT°C
WM  Ferrite = 68.39% Pearlite = 31.61%	**WM**  Ferrite = 71.40% Pearlite = 28.60%	**WM**  Ferrite = 63.46% Pearlite = 36.54%
HAZ  Ferrite = 70.60% Pearlite = 29.40%	**HAZ**  Ferrite = 65.87% Pearlite = 34.13%	**HAZ**  Ferrite = 65.00% Pearlite = 35.00%
BM  Ferrite = 72.52% Pearlite = 27.48%	**BM**  Ferrite = 73.13% Pearlite = 26.87%	**BM**  Ferrite = 72.28% Pearlite = 27.72%

Figure 9. Micro Structure Evaluation Result

In the percentage results seen in Figure 9, with the increase in PWHT temperature, the percentage of pearlite value decreases, and the ferrite phase increases. As the PWHT temperature increases, the increase and decrease in the percentage of ferrite and pearlite has an effect and this result is linear with the hardness value of a material. The higher the percentage of pearlite, the higher the hardness value, and vice versa when the ferrite percentage is higher, the material has softer properties. From the results of the micro-Vickers hardness test and micro examination, the hardness value is directly proportional to the composition of the pearlite and ferrite phases formed according to the PWHT temperature variations carried out after welding. The higher the density and dominance of the pearlite phase which is characterized by a dark color or tends to be black, the higher the hardness value of the material or specimen test area. And vice versa, the higher the density and dominance of the ferrite phase, the hardness value of a material or area tested, the lower the hardness value. This is because the pearlite phase has hard and strong properties [16].

4. CONCLUSION

From the overall testing of mechanical properties, namely tensile test, micro vickers hardness test, and microstructure, it is concluded that increasing PWHT temperature decreases the hardness value of a material which results in the tensile strength value of the material also decreasing. With increasing PWHT temperature, increasing the ductility of a material can be seen from the increasing elongation value seen in the strain significantly occurs in materials with PWHT 750 °C. This is linear with the increasing dominance of the ferrite phase and the decreasing pearlite phase in the material as the PWHT temperature increases. This phenomenon is evidenced by research conducted by Ghazali (2022) [17], which states that the high PWHT temperature affects the tensile strength, hardness value, and microstructure the higher the PWHT temperature, the lower the tensile strength, hardness value, and microstructure of the pearlite phase. The higher the PWHT temperature increases the ductility seen from the strain and the dominance of the ferrite phase increases.

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